# Mobile IoT platform and sensors for seat belt use detection and vehicle safety management system

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**ABSTRACT**

The correct use of seat belts reduces the risk of injury by 70% and the risk of death of occupants by 40% of a vehicle [1]. According to the Brazilian Association of Traffic Medicine, only 7% of passengers in rear seats buckle up [2]. The São Paulo State Transport Agency (ARTESP) indicates that 70% of traffic victims die without a seat belt worn [3], and according to a survey by ANTT (National Land Transport Agency), in the segment of buses and vans, 98% still ignore the use of seat belts when traveling [4].

Passenger safety is an issue to be addressed when it comes to transportation, and all around the world companies monitor assets with all sorts of technologies, but what about passengers?

This paper describes the methodology adopted by Analítica Engenharia to develop a novel platform (cellphone application, telemetry, and a Bluetooth low energy seat belt sensor) for monitoring, education, and passengers risk prevention of riding from cars to busses without properly wearing a seat belt.

A low-cost solution based on Internet of Things (IoT) framework of industry 4.0 has been developed, which is in line with today's digital transformation and embedded electronics for automotive solutions, as well as passenger safety according to Euro NCAP seat belt reminder protocol.

**INTRODUCTION**

Seat belt reminders (SBR's) play an important role changing user behavior regarding seat belt use. Studies show that over 80% of users who do not wear seat belts in vehicles without a SBR system do so in a car with a seat belt reminder that has a light signal associated to a loud and clear sound [5].

Studies show that sound is the most effective reminder, followed by icons, and text, the least effective [6]. Such studies have driven recent upgrades in the Insurance Institute for Highway Safety's (IIHS) new seat belt reminder rating program, rating the SBR as good, acceptable, marginal, or poor, based primarily on the volume, duration, and timing of the audible alert. Federal Motor Vehicle Safety Standards (FMVSS) No. 208 only requires SBR for front driver and passenger, but IIHS has initiated a rulemaking proceeding to amend it, and to require a seat belt warning system for rear seats.

Euro NCAP regulation requires an audible warning for rear seats in change-of-status (from buckled to unbuckled), a "Loud and Clear" audible signal is required, not requiring occupant detection for rear seats [7], scoring points are recorded for the presence of rear SBR and additional points for each rear seating position with occupant detection systems. In addition, all seating positions in vehicle categories $M_1$ and $N_1$ fitted with safety belts should que equipped with SBR as per UNECE R16, since September 2019 [8].

In Brazil the National Traffic Council (CONTRAN) established the SBR to be mandatory only for the driver and for all vehicles starting at 2023 [9]. Requirements for passengers and rear seats are equivalent to those established in UNECE R16 if SRBs are present.

Given the importance of wearing seat belts to prevent injuries and fatalities during an accident and the strong and positive impact of seat belt reminders, not only for drivers, but passengers as well [10], a novel system is proposed to allow for drivers and passengers an equal level of protection and awareness in all means of transportation where seat belts are necessary and installed.

Following the trends brought by the growth of the IoT devices along with smartphones - actually, authors point that the main catalyst for the IoT growth will be the smartphone - operating systems (OS) and sensors, vehicle related digital services have been encompassed by the digital transformation chain in the automotive industry, driving an unprecedented number of applications with devices connected, since from safe driver identification to vehicle maintenance for insurance companies' actuarial algorithms [11].

The present system works with portable devices, such as smartphones, in communication with the developed mobile application [12] via Bluetooth Low Energy (BLE) protocol [13], in addition, it has the option of a Sensor Tape (ST), which detects the presence of the occupant allowing the seat belt sensor to check the belt state when the occupant presence is confirmed (Integral Mode) or just advertise the change-of-status to the mobile application when the ST is not required or installed (Educative Mode).

When in the Educative Mode, which comprises most of the scenarios, the system does not require the installation of additional components than those depicted in Figure 1: The (**i**) seat belt sensor and the (**ii**) mobile Application.


Figure 1. The patent application overview [14].

## DESIGN PRINCIPLES - HARDWARE

The Seat Belt Sensor – Being the heart of the system (figure 2), it´s packed with heat resistant plastic top and bottom covers joined by fastening elements, produced by injection molding with IP65 encapsulation (dustproof and protected against water jets) [15]. It has a discreet design, easy to attach to the buckle via a simple three steps procedure with the adhesive tape (figure 3).

The seatbelt sensor contains a magnetic sensor switch(*) coupled with a biasing magnet element for a calibrated, low hysteresis, unit by unit, omnipolar magnetic field response. When in the presence of ferrous materials (seat belt tongue/buckle) it allows the detection of the seat belt fastening by the occupant. It also has a battery and a programmable BLE module, which contains the firmware (software) and operating logic developed specifically for this device, with a low energy Bluetooth radio system and transmitting antenna.

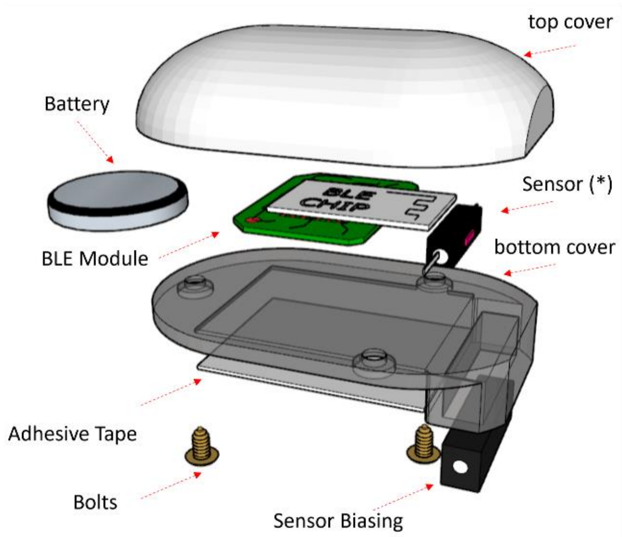


Figure 2. The seat belt sensor [14].

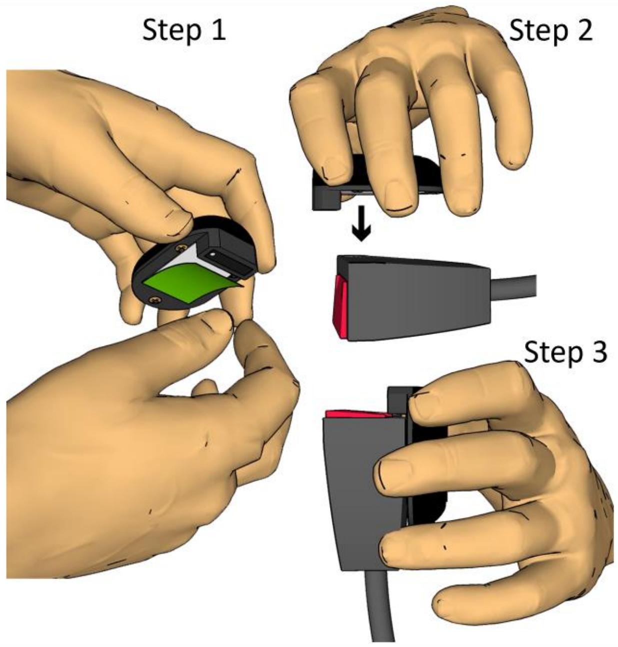


Figure 3. Three steps seat belt sensor mounting [14].

The automotive industry requires interior systems certifications, among those: (**i**) Shock and vibration, resistant mechanical and environmental loads [16] – which has direct influence on the sensor switch(*) type choice, between reed sensors, hall effect switches or solid-state magneto resistive types, (**ii**) Electromagnetic compatibility – the BLE module shall comply to Part 15 of Federal Communications Commission (FCC) or the equivalent European Union designated Conformitè Europëenne (CE) [17] in order to be accepted by Brazilian Telecommunication Regulatory Agency (ANATEL), as well as comply to the Bluetooth SIG certification program [13] and this is directly connected to the complete hardware (end product) design, (**iii**) Fire propagation (FMVSS 302) burn rate test [18] impacts the encapsulation materials choice as well as (**iv**) Restriction of Hazardous Substances (RoHS), an European directive which regulates the use of hazardous substances in electronic and electrical equipment, such as the Printed Circuit Boards (PCB) where all the electronic components are assembled and at last, but not least, (**v**) Batteries to ensure their safe operation under intended use and reasonably foreseeable misuse [19]. All the requirements above impose tight restrictions on the Hardware side of the IoT solutions development for the automotive market and must be properly addressed.

The Sensor Tape (ST) – Sensor Tape (ST), although not necessary in the Educative Mode, plays a major function in the present system [14] when in the Integral Mode, which involves the use of such sensor, playing a key role in occupant detection, initiating the monitoring algorithm by the Seat Belt Sensor.

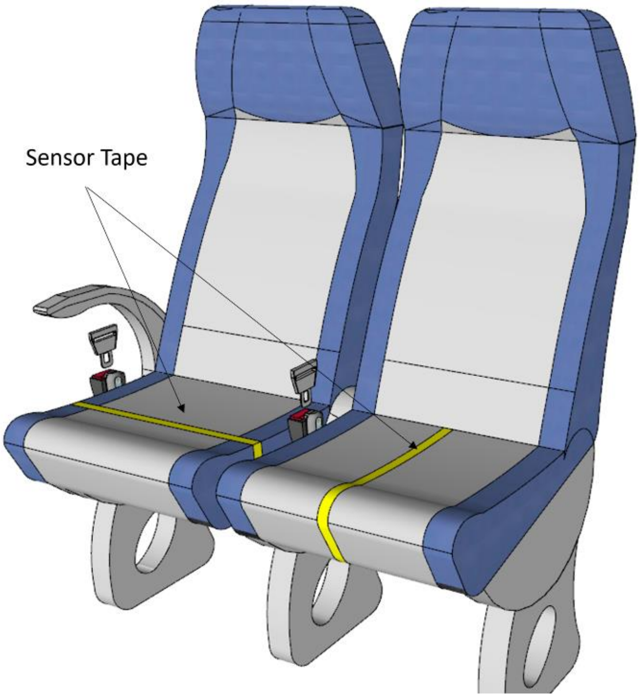


Figure 4. Sensor tape installation.

The sensor tape can be positioned longitudinally, transversally to the seat. This tape, as shown in figures 4 and 5, has an electrical wire with a two-way connector connecting it to the device (Seat Belt Sensor), in addition to a flexible cord in fabric or leather, which counts with rivet fixing and an adjustment knob to accommodate the most diverse automotive seats, also known as a cord or elastic pass adjuster. It is important to point out that occupants do not have access to the adjustment knob, preventing vandalism or theft in cases of institutional application.

The sensor tape, as shown in figure 5, is composed of a combination of (**a**) fabrics with lower and upper finishes, which are resistant to abrasion and are available in a variety of colors, from discrete to eye-catching colors, alerting users to the presence of the device; (**b**) conductive fabrics, which are flexible and resistant, impregnated with silver and (**c**) the conductive graphite film, which allows the flow of electric current when the sensor tape is exposed to pressure patterns from the presence of the occupant.

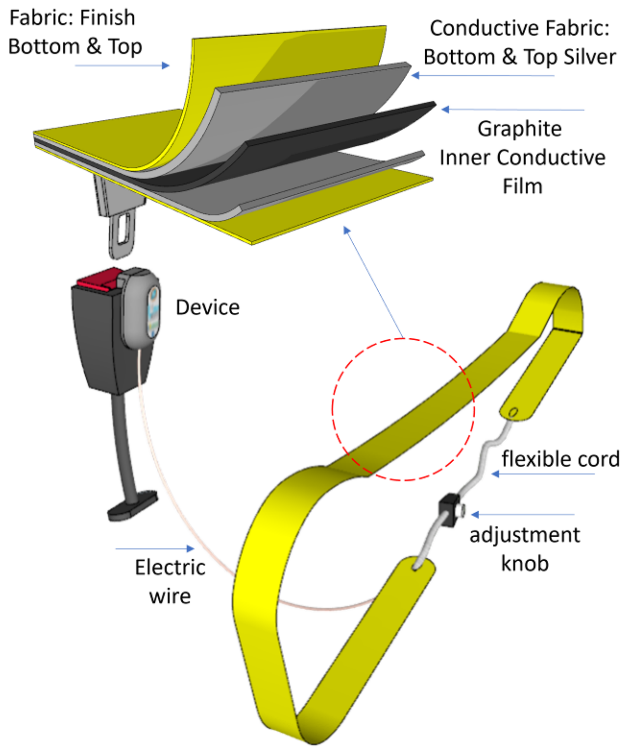


Figure 5. Sensor tape details.

When sitting on the sensor tape the device initializes the algorithm programmed in its BLE Module, performing the sensing activities, and communicating via BLE with the Application.

Figure 6 shows H-Point-Manikin (HPM), which is an essential tool for the correct measurements and dummy positioning for many test applications. The HPM fulfills the SAE J826 [20] and has been used in this development to validate the sensor tape detection for a variety of occupants and seat configurations aiming zero false alarms scenarios.

Occupant detection in the automotive industry requires seats that contain weight sensors, these, previously installed by seat manufacturers and placed inside the seat, in addition to programmed electronic modules, cabling and additional connectors, making the detection of passengers or drivers, a step considered expensive by the automotive industry.

Throughout several laboratory studies with the measurement of occupant comfort for the transportation industry, through the analysis of the pressure maps exposed in Figure 6, this low-cost solution was developed, which has a sensor tape, detecting the presence of occupants through conductive and semi-conductive fabrics. This combination, in addition to providing great durability to fatigue and flexibility, does not interfere with occupant comfort and ensures the device receives the occupant detection information and informs the system of the status of that seat, whether the seat belt is buckled or not.

The sensor tape is completely flexible, composed of fabrics and accommodates the most different shapes of automotive seats, thus providing the operation of the Integral Mode, which allows the driver and the system to recognize the presence of the occupant, and whether the occupant is wearing a seat belt, performing a full occupant safety check per the seat belt warning protocol.

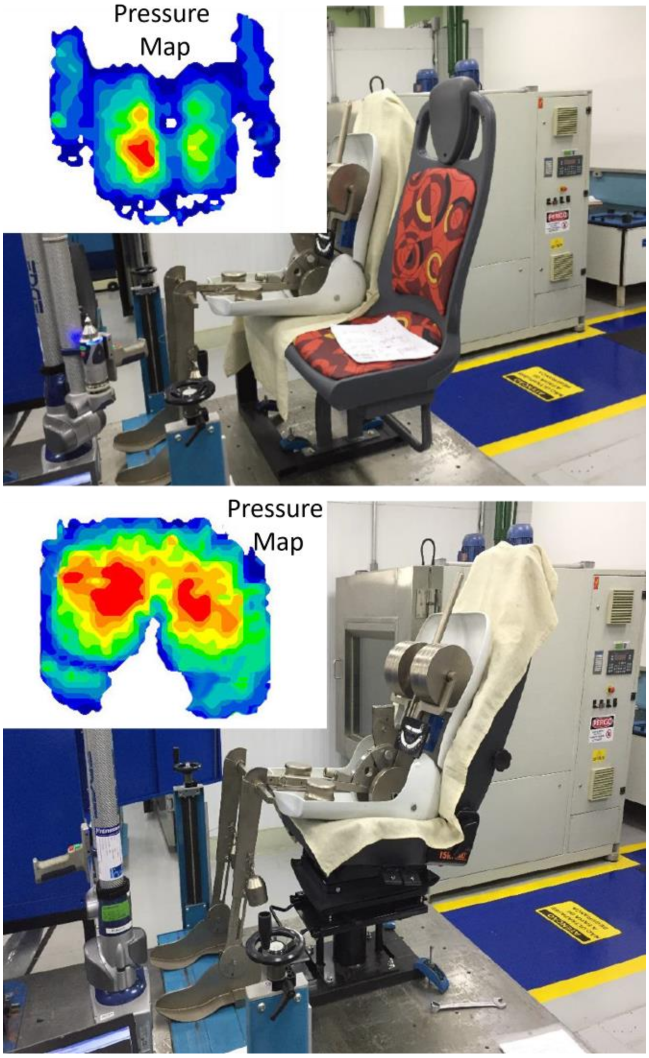


Figure 6. Map pressure tests with bus seats.

## DESIGN PRINCIPLES - SOFTWARE

<u>The Seat Belt Sensor Firmware</u> – The Seat Belt Sensor device was developed with Bluetooth Low Energy technology (BLE) and it can communicate with the most diverse smartphones, tablets or smart devices available in the market with operating systems like Android or iOS.

The flowchart algorithm for the firmware is depicted in figure 7. This application requires very low energy consumption, which can be achieved by using (**i**) BLE low consumption modules; Nordic nRF52 family SoCs [21], (**ii**) a portable and flexible Real Time Operating System (RTOS); Zephyr [22] allowing for parallel threads to run, being capable of allowing the system to be deterministic and granting levels of latency by its kernel, optimized for resource-constrained embedded devices and built with security top practices, task control, etc., and (**iii**) a smart General Purpose Input/Output (GPIO) sensing configuration, which drains current only when seat belt change-of-state is detected, turning (On) and (Off) the right pull up SoC internal resistor, entering in power modes Low and Off with the Zephyr Power Management subsystem.

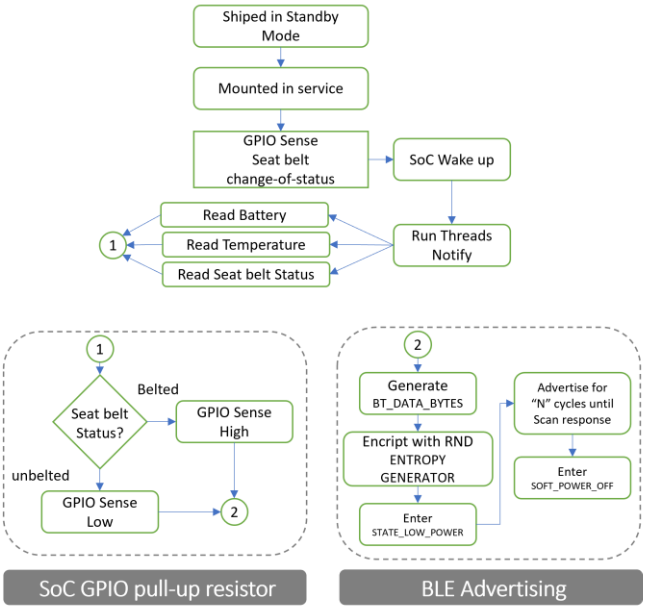


Figure 7. Firmware algorithm flow chart.

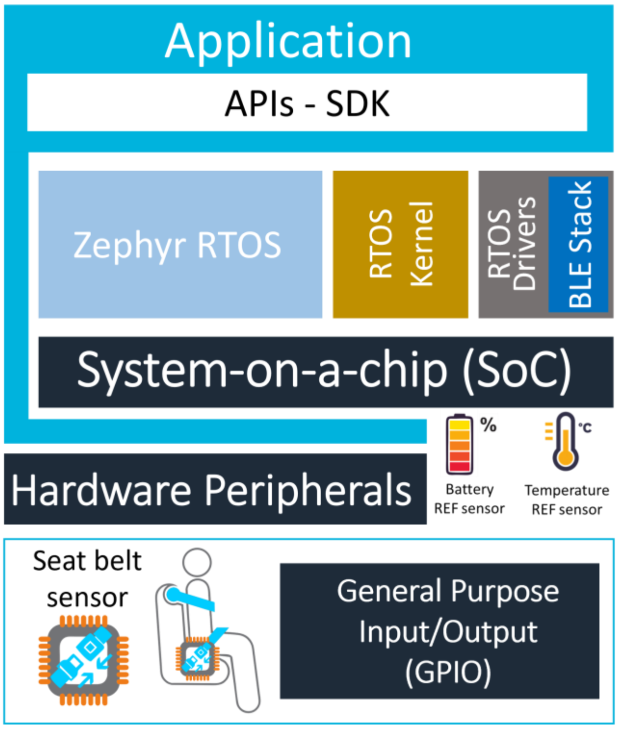


Figure 8. Zephyr RTOS and Nordic framework with Analítica SBR system for safety passenger transportation.

Zephyr, associated to the Nordic API environment framework, applied to Analítica SBR developed can be visualized in figure 8.

The Smartphone Application – A flowchart of the smartphone application can be seen at figure 9. Like any smartphone application, its required to allow for the user to:

(**a**) Read short instructions on how to mount and configure (pair) the SBR sensors to the right seat it is installed,

(**b**) Allow the Application permissions for services like; (**i**) Fine Location for the Bluetooth and location services to work properly, (**ii**) Camera permission to unlock the Application – This solution has been made available free in Google Play Store [12] but once it requires a hardware to work (the Seat Belt Sensor) the user needs a Quick Response (QR) code, which is shipped together to unlock the Application, avoiding a bad experience for the general public who do not have the Seat Belt Sensor,

(**c**) User account creation and authentication, with servicers like; (**i**) Support for forgotten passwords, (**ii**) User engagement via Application notifications and messaging and (**iii**) Soft updates, where the application changes its behavior according to predefined user engagement to a market campaign.

After the user creates an account, the next steps are very simple, consisting of (**1.0**) Vehicle Type selection and (**1.1**) vehicle Layout option, like figures 10 and 11.

When designing the IoT solution, (**i**) Interoperability, (**ii**) Scalability, and (**iii**) Security are on the top of the challenges for the system development [23] and must be properly addressed.

(**i**) Interoperability: Different technologies, protocols and architectures should communicate with each other. The idea of IoT is that new devices and objects can be added without major changes to the established network. A network topology where the smartphone application publishes all the data to a Broker (Server) via Message Queue Telemetry Transport (MQTT) protocol [24] guarantees Interoperability of the system. This is an open protocol designed to be simple, light, and easy to implement: features suitable for devices embedded with memory and/or processing resources limited.

(**ii**) Scalability: Events can be produced or consumed in asynchronously, allowing for greater scalability to the system, as well as solutions where low battery consumption is a prerequisite, and where there is little available bandwidth or intermittent connection, like it happens in a vehicle, changing cellphone reception towers during a trip.

(iii) Safety: MQTT has issues considering security once it uses Secure Sockets Layer (SSL) or Transport Layer Security (TLS) for security. When a message is sent to the broker, the username and password can be used for authentication, in the present application the authentication token not fixed and changes via a 3rd part API service, providing MQTT 5.0 compliance [25], allowing an extra layer of safety.

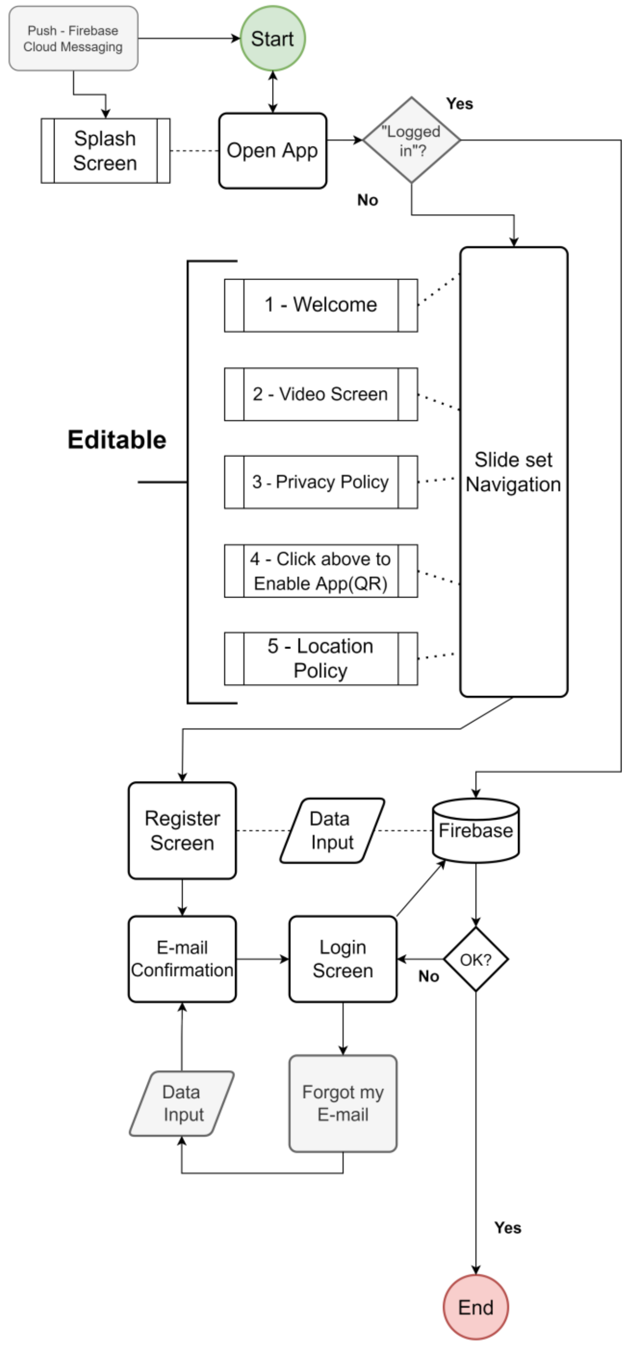


Figure 9: Intro Screens of flowchart of the smartphone application


Figure 10: Vehicle Type selection

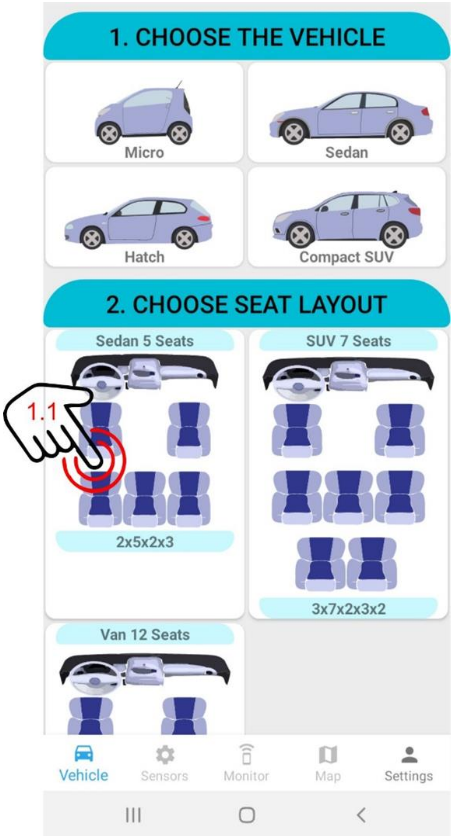


Figure 11: Vehicle Layout options

After the steps (**1.0**) Vehicle Type selection and (**1.1**) vehicle Layout option, the user is directed to the pairing section (**1.2**) and the sensors are already installed, just a latching-unlatching of the seat belt is enough for the Seat Bent Sensor to start the advertisement for the right seat pairing.

The system searches for nearby devices and records the state of each installed belt (whether buckled or not) in addition to the device's battery level (indicating the user the need for replacement when discharged) and the proper seat temperature and surroundings (which is being used in the comfort analysis of multi passenger transportation).

The platform [14] was developed to work together with the system in two operating modes: Educative Mode and Integral Mode.

Once the system is monitoring in Educative Mode, if the passenger releases the seat belt while the vehicle is in motion, a 30-second duration beep is activated if reaching a speed of 25 km/h or after traveling 500 meters at a speed below 25 km/h - this is when any occupied seat has a change-of-status while traveling. The system also includes audible and visual warnings when rear seat belts are unfastened while the vehicle is in motion - an unlikely scenario for false alarms.

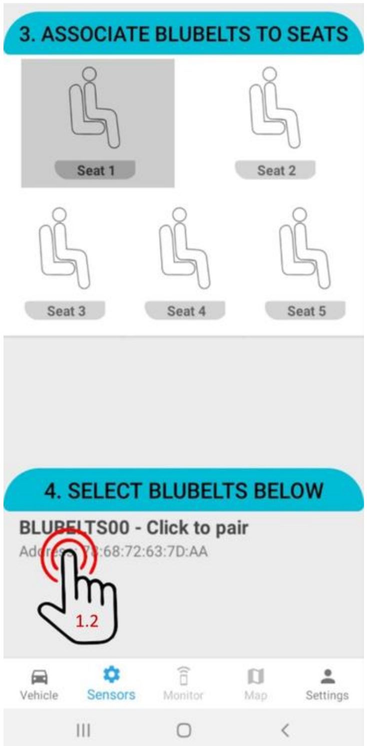


Figure 12: Sensor seat pairing

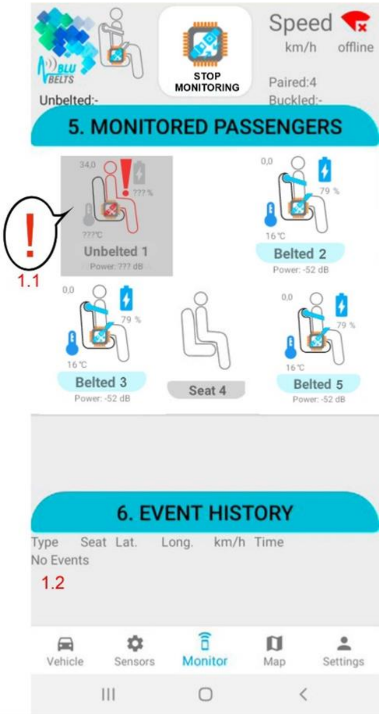

Figure 13: System paired and monitoring

In addition, when any seat belt undergoes a status change at vehicle speeds above 25 km/h, an audiovisual signal is provided to the driver in accordance with the seat belt reminder protocol and the driver has an easily accessible visual indication, at all times, of all seats and which passengers are or “are not” wearing their seat belts without the need to turn around and/or walk around the vehicle by visually checking if the seat belts are fastened.

The driver has video and audio indication when violations occur, and the system also has a telemetry solution (Telephony or Satellite) for managers and HSE (Health, Safety and Environment) personnel with reports and statistics for drivers and coaching of passengers. One solution for kids’ transportation in buses or vans has also been developed.

The platform works independently, that is, the driver can even close the application, and turn off the smartphone screen, yet it will still monitor the safety of passengers. That´s because the Application starts a Foreground Service [26] which is transparent to the user but never killed unless (**i**) the smartphone is turned off or (**ii**) the user turns off the monitoring service, which is an option made available by law in all vehicles equipped with seat belt reminders (SBR).

## THE SYSTEM MODES

EDUCATIVE MODE – In this mode, the device is installed without the sensor tape, only detecting (and visually indicating to the driver how many devices are installed in the seats, how many are buckled and the quantity and location of the buckled belts) change-of-status, in addition to monitoring the speed and location of the vehicle, following the safety protocols [7-10].

It has sound signals (through a female audio voice message synthesized by the Application on the smartphone, tablet or similar - including the vehicle's audio system, in the scenario where the vehicle already has its audio system paired to the smartphone - followed by an audible bell) and visual signals (with indication on the smartphone screen which seat the event refers to) are emitted to the driver if during the journey any seat belt suffers a "change-of-status", where a buckled belt changes to unbuckled status with the vehicle moving (audiovisual) or stationary (visual indication only).

When a seat belt undergoes a change in status from “buckled” to “unbuckled” and the vehicle is traveling at a speed equal to or greater than 25 km/h, the audiovisual signal is emitted, once the driver may be careful because there is an occupant with the uncoupled restraint system during the journey, allowing the necessary safety measures to be taken. When such events occur, the system sends information via the MQTT protocol to broker about the location, speed and in which seat the event occurred to the telemetry platform and online management, via transmission towers and/or satellite. which generates reports with events and location statistics allowing corrective measures to be planned and disseminated.

Vulnerable Forgetting Function – The Educative Mode also has a vulnerable Forgetting Function (VFF) illustrated in figure 14: If the holder of a smartphone, tablet or similar distances more than 20 meters away from the vehicle, and this mode is set, the Application (which keeps on track with the signal strength indicator (RSSI) in this mode) creates an audiovisual signal which alerts the driver (smartphone holder) that the vehicle has a vulnerable being forgotten with the belt buckled.

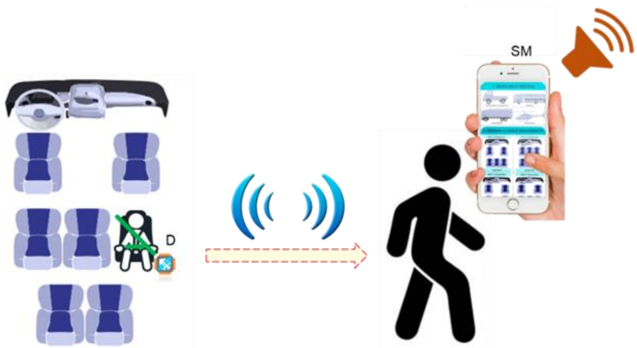

Figure 14: Vulnerable forgetting function

Safe Kids Transportation – In addition to the Educative Mode, a new feature for safe kids’ transportation by 3$^{rd}$ parties in buses or vans has also been developed.

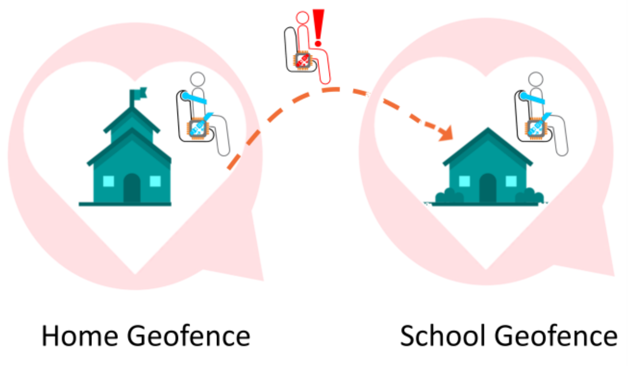


Figure 15: Safe kids Transportation

The application creates a 50 meters geofence every time a seat belt is bucked and unbuckled in a neighborhood. If that pattern remains repetitive for more than 5 times the platform registers "Kid (a) Home GeoLocation buckled in seat (n)" and latter "Kid (a) School GeoLocation unbuckled the same seat (n)". Tests indicate that between 5 to 10 events generate a 90% assertiveness, directly related to the GPS smartphone quality and urban density.

With this algorithm running on the IoT/telematics hub [25] parents may be made aware of the following information on exactly which kids from which neighborhood: (**i**) are not using seatbelts regularly between home and school and (**ii**) are releasing the seat belts with the vehicle in movement.

INTEGRAL MODE – In this scenario, the device is installed with the sensor tape, and, in addition to the status change verification, and all the audiovisual indication of the status of each seat to the driver on the application screen, described in Educative Mode, the system now has full indication of the effective presence of occupants and which ones use seat belts or not, issuing alerts in scenarios where:

(**i**) The vehicle has been in "Forward Drive" for 60 seconds without the seat belt fastened, or

(**ii**) The vehicle has been in "Forward Drive" for 500 meters without the seat belt fastened, or

(**iii**) The vehicle has reached a forward speed of 25 km/h without the seat belt fastened.

## ADVANTAGES OF THE SYSTEM

It is well known that passenger transportation vehicles, from small cars, here, included the largest urban digital ride/taxi mobile platforms, to aircrafts, do not have SBR monitoring systems for all occupants, and given that the correct use of seat belts reduces the risk of injuries in vehicle occupants, this novel platform covers this gap in the market in terms of vehicle safety, where, although similar solutions exist, they do not reach the technological level incorporated into this product.

In this context and based on research and analysis of the state of the art aimed at vehicle safety and comfort, embedded systems and mobile services, a solution that can be easily attached to seat belts was developed [14], having sensors, wireless communication, and embedded systems for using in in conjunction with smartphones, tablets or in-vehicle multimedia systems. Thus, the driver/user can install the devices on the vehicle's belts and, through the system, start monitoring all relevant and regulatory [7-10] events.

Safety in passenger transportation, which moves millions of passengers daily, whether by means of buses, trucks and vans or small vehicles, can combine safety and comfort for its passengers (the devices report temperature, which can be used to improve passenger comfort as well). Tests were also carried out to ensure distancing between occupants during passenger transportation in case this scenario is necessary.

Financially, the reduction of injuries and time off costs in small accidents and caused by the lack or wrong use of seat belts, already guarantees the economic return to the company or even parents adopting this platform.

With the system, individuals, employees, as well as managers and companies from the most varied sectors, are guaranteed to control the risks involved in passenger transportation, and it is an exceptional tool that will even position the values of a company to the market and society.

Some advantages can be highlighted here:

• Simple installation in Educative Mode, just attach the device to the seat belt and it's ready to use,

• User detection and integral monitoring with sensor tape available,

• It does not need other devices, only the driver/user personal smartphone device to work,

• The system warns about the possible forgetting of a vulnerable person in the vehicle, and has a learning protocol to track kids seat belt behavior between home and school when 3rd parties are evolved,

• The system generates event reports and maintains an online management of occurrences, with seats, events, location, speed and other variables,

• Indicates ambient temperature and battery level (warning the user when it needs to be replaced).

## EXAMPLE OF APPLICATION

The device was installed for testing in a unit used in environmental monitoring activities, which require displacement in remote areas and satellite telemetry, in addition to monitoring the use of seat belts with the device.

In this application, the system was customized to record SSMA – Health, Safety and Environment activities, such as Daily Safety Dialogues, Vehicle Checklist, among other forms scanned and incorporated into the Application. An in-ear fatigue monitoring sensor via Bluetooth was also integrated into the solution.

The most direct results are translated by the improvement in the digitization of processes related to SSMA and in the positioning of the company in relation to the environmental monitoring market, and its employees, who have come to understand that the company's investments reflect concern and professionalism in the face of to the lives of drivers and passengers. Not only drivers but also passengers know that not just the vehicle is monitored, but also their behavior when using seat belts.

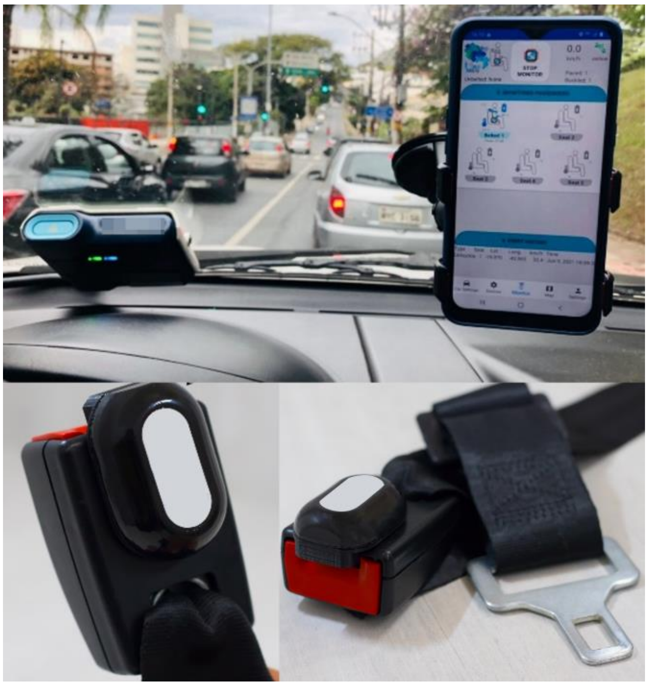

Figure 16: Application Example

It is important to note that the figures and description made do not have the power to limit the forms of execution of the inventive concept demonstrated in this article, but rather to illustrate and make understandable the conceptual innovations revealed in this solution. Thus, the descriptions and images must be interpreted in non-limiting manner, and there may be other equivalent or similar ways of implementing the inventive concept now revealed and that do not deviate from the protection spectrum outlined in the proposed solution.

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